

Interference Suppression Film Capacitor - Class X1

Radial MKP 440 V_{AC} - Standard Across the Line



FEATURES

- 15 mm to 27.5 mm lead pitch
- 440 V rated AC voltage
- Material categorization: for definitions of compliance please see www.vishay.com/doc?99912


RoHS
COMPLIANT

APPLICATIONS

For standard across the line X1 applications.

See also application note: www.vishay.com/doc?28153

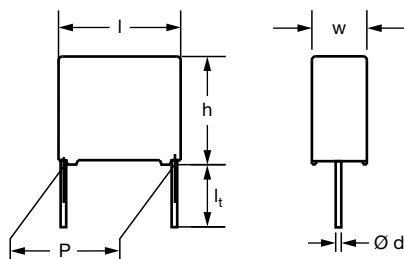
QUICK REFERENCE DATA

Capacitance range (E12 series)	0.01 μ F to 1 μ F (referred values acc. to E6)
Capacitance tolerance	$\pm 20\%$, $\pm 10\%$, $\pm 5\%$
Rated AC voltage	440 V _{AC} ; 50 Hz to 60 Hz
Permissible DC voltage	1000 V _{DC}
Climatic testing class acc. to IEC 60068-1	50/105/56/C for product volumes > 1750 mm ³ 50/105/56/B for volumes $\leq$ 1750 mm ³
Maximum application temperature	105 °C
Reference standards	IEC 60384-14 ed-4 (2013) and EN 60384-14 IEC 60065 pass. flamm. class B for volumes > 1750 mm ³ UL 60384-14
Dielectric	Polypropylene film
Electrodes	Metallized film
Construction	Mono construction
Encapsulation	Plastic case, epoxy resin sealed, flame retardant UL-class 94 V-0
Leads	Tinned wire
Marking	C-value; tolerance; rated voltage; sub-class; manufacturer's type; code for dielectric material; manufacturer location, year and week; manufacturer's logo or name; safety approvals

Note

- For more detailed data and test requirements, contact rfi@vishay.com

DIMENSIONS





COMPOSITION OF CATALOG NUMBER

TYPE AND PITCHES		CAPACITANCE (numerically)		MULTIPLIER (nF)	
338 1	15.0 mm	Example: 104 = 10 x 10 = 100 nF (except special numbers)	BFC2	0.1	2
X1	22.5 mm			1	3
	27.5 mm			10	4
				100	5
		338 1X XX X			
TYPE	PACKAGING	LEAD CONFIGURATION	C-TOL.	PREFERRED TYPES	
338 1 X1	Loose in box	Lead length 3.5 mm ± 0.3 mm	± 20 %	BFC2 338 10 ...	
		Lead length 5.0 mm ± 1.0 mm		BFC2 338 12 ...	
		Lead length 25.0 mm ± 2.0 mm		BFC2 338 14 ...	
	Taped on reel ⁽¹⁾	H = 18.5 mm; for P ₀ = 12.7 mm; reel diameter = 500 mm		BFC2 338 17 ...	
TYPE	PACKAGING	ALTERNATIVE C-TOL.	C-TOL.	ON REQUEST	
338 1 X1	Loose in box	Lead length 3.5 mm ± 0.3 mm	± 10 %	See tables for detail	
			± 5 %		
		Lead length 5.0 mm ± 1.0 mm	± 10 %		
			± 5 %		
	Taped on reel ⁽¹⁾	Lead length 25.0 mm ± 2.0 mm	± 10 %		
			± 5 %		
		H = 18.5 mm; P ₀ = 12.7 mm; reel diameter = 500 mm	± 10 %		
			± 5 %		

Note

⁽¹⁾ For detailed tape specification refer to packaging information: www.vishay.com/doc?28139

SPECIFIC REFERENCE DATA		
DESCRIPTION	VALUE	
Rated AC voltage (U _{RAC})	440 V	
Permissible DC voltage (U _{RDC})	1000 V	
Tangent of loss angle:	at 1 kHz	at 10 kHz
C ≤ 470 nF	≤ 10 x 10 ⁻⁴	≤ 20 x 10 ⁻⁴
C > 470 nF	≤ 20 x 10 ⁻⁴	≤ 70 x 10 ⁻⁴
Rated voltage pulse slope (dU/dt) _R at 615 V _{DC}		
Pitch = 15 mm	250 V/μs	
Pitch = 22.5 mm	150 V/μs	
Pitch = 27.5 mm	100 V/μs	
R between leads, for C ≤ 0.33 μF at 100 V, 1 min	> 15 000 MΩ	
RC between leads, for C > 0.33 μF at 100 V, 1 min	> 5000 s	
R between leads and case, 100 V, 1 min	> 30 000 MΩ	
Withstanding (DC) voltage (cut off current 10 mA) ⁽¹⁾ , rise time ≤ 1000 V/s	3400 V, 1 min	
Withstanding (AC) voltage between leads and case	2380 V, 1 min	
Maximum application temperature	105 °C	

Note

⁽¹⁾ See "Voltage Proof Test for Metallized Film Capacitors": www.vishay.com/doc?28169



ELECTRICAL DATA AND ORDERING INFORMATION															
U _{RAC}	CAP. (μF)	DIMENSIONS w x h x l (mm)	MASS (g) ⁽³⁾	CATALOG NUMBER BFC2 338 1XXXX AND PACKAGING											
				LOOSE IN BOX					TAPED REEL ⁽¹⁾⁽²⁾						
				SHORT LEADS			LONG LEADS		Ø = 500 mm						
				l _t = 3.5 mm ± 0.3 mm	l _t = 5.0 mm ± 1.0 mm	SPQ	l _t = 25.0 mm ± 2.0 mm	SPQ	H = 18.5 mm; P ₀ = 12.7 mm	SPQ					
440	PITCH = 15.0 mm ± 0.4 mm; d _t = 0.60 mm ± 0.06 mm; C-tol. = ± 20 %														
	0.010 0.012 0.015 0.018 0.022	5.0 x 11.0 x 17.5	1.0	10103 10123 10153 10183 10223	12103 12123 12153 12183 12223	1000	14103 14123 14153 14183 14223	1000	17103 17123 17153 17183 17223	1100					
	0.027 0.033			6.0 x 12.0 x 17.5	1.4		10273 10333		12273 12333		1000	14273 14333	1000	17273 17333	900
	PITCH = 15.0 mm ± 0.4 mm; d _t = 0.80 mm ± 0.08 mm; C-tol. = ± 20 %														
	0.039 0.047			7.0 x 13.5 x 17.5	1.8		10393 10473		12393 12473		750	14393 14473	500	17393 17473	800
	0.056 0.068						8.5 x 15.0 x 17.5		2.4			10563 10683		12563 12683	
	0.082 0.10	10.0 x 16.5 x 17.5	3.0	10823 10104	12823 12104	500		14823 14104		450	17823 17104	600			
	PITCH = 22.5 mm ± 0.4 mm; d _t = 0.80 mm ± 0.08 mm; C-tol. = ± 20 %														
	0.12 0.15	8.5 x 18.0 x 26.0	3.8	10124 10154	12124 12154	200	14124 14154	250	17124 17154	450					
	0.18 0.22			10.0 x 19.5 x 26.0	6.8		10184 10224		12184 12224		200	14184 14224	200	17184 17224	350
	PITCH = 27.5 mm ± 0.4 mm; d _t = 0.80 mm ± 0.08 mm; C-tol. = ± 20 %														
	0.27 0.33 0.39 0.47	11.0 x 21.0 x 31.0 13.0 x 23.0 x 31.0 15.0 x 25.0 x 31.5 15.0 x 25.0 x 31.5	7.4 9.2 12.3 12.3	10274 10334 10394 10474	12274 12334 12394 12474	100 100 100 100	14274 14334 14394 14474	125 125 125 125	-	-					
	0.56 0.68	18.0 x 28.0 x 31.5	16.1	10564 10684	12564 12684	100	14564 14684	100							
	0.82 1.00			21.0 x 31.0 x 31.0	20.3		10824 10105				12824 12105	50	14824 14105	75	
	PITCH = 15.0 mm ± 0.4 mm; d _t = 0.60 mm ± 0.06 mm; C-tol. = ± 10 %														
	0.010 0.012 0.015 0.018	5.0 x 11.0 x 17.5	1.0	18114 18115 18116 18117	18314 18315 18316 18317	1000	18514 18515 18516 18517	1000			18914 18915 18916 18917	1100			
	0.022 0.027			6.0 x 12.0 x 17.5	1.4		18118 18119		18318 18319	1000	18518 18519		1000	18918 18919	900
	PITCH = 15.0 mm ± 0.4 mm; d _t = 0.80 mm ± 0.08 mm; C-tol. = ± 10 %														
	0.033 0.039			7.0 x 13.5 x 17.5	1.8		18121 18122		18321 18322	750	18521 18522		500	18921 18922	800
	0.047 0.056	8.5 x 15.0 x 17.5	2.4			18123 18124	18323 18324	750	18523 18524		500	18923 18924		650	
	0.068 0.082			10.0 x 16.5 x 17.5	3.0	18125 18126	18325 18326		500	18525 18526		450	18925 18926		600



ELECTRICAL DATA AND ORDERING INFORMATION

U _{RAC}	CAP. (μF)	DIMENSIONS w x h x l (mm)	MASS (g) ⁽³⁾	CATALOG NUMBER BFC2 338 1XXXX AND PACKAGING							
				LOOSE IN BOX					TAPED REEL ⁽¹⁾⁽²⁾		
				SHORT LEADS			LONG LEADS		Ø = 500 mm		
				l _t = 3.5 mm ± 0.3 mm	l _t = 5.0 mm ± 1.0 mm	SPQ	l _t = 25.0 mm ± 2.0 mm	SPQ	H = 18.5 mm; P ₀ = 12.7 mm	SPQ	
440	PITCH = 22.5 mm ± 0.4 mm; d _t = 0.80 mm ± 0.08 mm; C-tol. = ± 10 %										
	0.10	7.0 x 16.5 x 26.0	2.9	18127	18327	200	18527	250	18927	550	
	0.12	8.5 x 18.0 x 26.0	3.8	18128	18328	200	18528	250	18928	450	
	0.15			18129	18329		18529		18929		
	0.18	10.0 x 19.5 x 26.0	6.8	18131	18331	200	18531	200	18931	350	
	PITCH = 27.5 mm ± 0.4 mm; d _t = 0.80 mm ± 0.08 mm; C-tol. = ± 10 %										
	0.22	11.0 x 21.0 x 31.0	7.4	18132	18332	100	18532	125	-	-	
	0.27			18133	18333		18533				
	0.33	13.0 x 23.0 x 31.0	9.2	18134	18334	100	18534	125			
	0.39	15.0 x 25.0 x 31.0	12.3	18135	18335	100	18535	125			
	0.47			18136	18336		18536				
	0.56	18.0 x 28.0 x 31.0	16.1	18137	18337	100	18537	100			
	0.68			18138	18338		18538				
	0.82	21.0 x 31.0 x 31.0	20.3	18139	18339	50	18539	75			
	PITCH = 15.0 mm ± 0.4 mm; d _t = 0.60 mm ± 0.06 mm; C-tol. = ± 5 %										
	0.010	5.0 x 11.0 x 17.5	1.0	18214	18414	1000	18614	1000	18934	1100	
	0.012			18215	18415		18615		18935		
	0.015			18216	18416		18616		18936		
	0.018			18217	18417		18617		18937		
	0.022	6.0 x 12.0 x 17.5	1.4	18218	18418	1000	18618	1000	18938	900	
	0.027			18219	18419		18619		18939		
	PITCH = 15.0 mm ± 0.4 mm; d _t = 0.80 mm ± 0.08 mm; C-tol. = ± 5 %										
	0.033	7.0 x 13.5 x 17.5	1.8	18221	18421	750	18621	500	18941	800	
	0.039			18222	18422		18622		18942		
	0.047	8.5 x 15.0 x 17.5	2.4	18223	18423	750	18623	500	18943	650	
	0.056			18224	18424		18624		18944		
	0.068	10.0 x 16.5 x 17.5	3.0	18225	18425	500	18625	450	18945	600	
	0.082			18226	18426		18626		18946		
	PITCH = 22.5 mm ± 0.4 mm; d _t = 0.80 mm ± 0.08 mm; C-tol. = ± 5 %										
	0.10	8.5 x 18.0 x 26.0	3.8	18227	18427	200	18627	250	18947	450	
	0.12			18228	18428		18628		18948		
	0.15	10.0 x 19.5 x 26.0	6.8	18229	18429	200	18629	200	18949	350	
	0.18			18231	18431		18631		18951		
	PITCH = 27.5 mm ± 0.4 mm; d _t = 0.80 mm ± 0.08 mm; C-tol. = ± 5 %										
	0.22	11.0 x 21.0 x 31.0	7.4	18232	18432	100	18632	125	-	-	
	0.27	13.0 x 23.0 x 31.0	9.2	18233	18433	100	18633	125			
	0.33			18234	18434		18634				
	0.39	15.0 x 25.0 x 31.5	12.3	18235	18435	100	18635	125			
	0.47			18236	18436		18636				
	0.56	18.0 x 28.0 x 31.5	16.1	18237	18437	100	18637	100			
	0.68			18238	18438		18638				
	0.82	21.0 x 31.0 x 31.0	20.3	18239	18439	50	18639	75			

Notes

- SPQ = Standard Packing Quantity

(1) H = in-tape height; P₀ = sprocket hole distance; for detailed specifications refer to packaging information: www.vishay.com/doc?28139

(2) Reel diameter = 356 mm is available on request

(3) Weight for short lead product only

APPROVALS				
SAFETY APPROVALS X1	VOLTAGE	VALUE	FILE NUMBERS	LINKS
EN 60384-14 (ENEC) (= IEC 60384-14 ed-4 (2013))	440 V _{AC}	10 nF to 1 µF	ENEC16/FI/19/10003	www.vishay.com/doc?28202
UL 60384-14	440 V _{AC}	10 nF to 1 µF	E354331	www.vishay.com/doc?28190
CSA E384-14	440 V _{AC}	10 nF to 1 µF	E354331	
CB-test certificate	440 V _{AC}	10 nF to 1 µF	FI-39829	www.vishay.com/doc?28201
The ENEC-approval together with the CB-certificate replace all national marks of the following countries (they have already signed the ENEC-agreement): Austria; Belgium; Czech. Republic; Denmark; Finland; France; Germany; Greece; Hungary; Ireland; Italy; Luxembourg; Netherlands; Norway; Portugal; Slovenian; Spain; Switzerland and United Kingdom.				
 				

MOUNTING

Normal Use

The capacitors are designed for mounting on printed-circuit boards. The capacitors packed in bandoleers are designed for mounting in printed-circuit boards by means of automatic insertion machines.

For detailed tape specifications refer to packaging information: www.vishay.com/doc?28139

Specific Method of Mounting to Withstand Vibration and Shock

In order to withstand vibration and shock tests, it must be ensured that the stand-off pips are in good contact with the printed-circuit board:

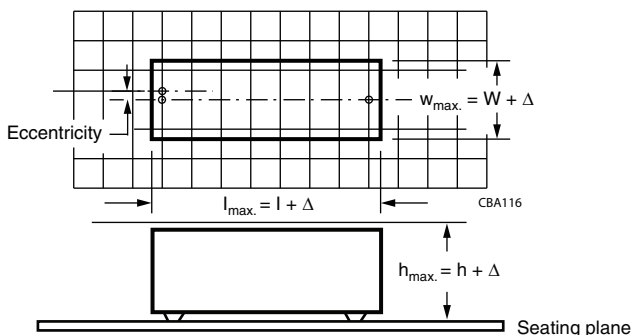
- For pitches ≤ 15 mm capacitors shall be mechanically fixed by the leads
- For longer pitches the capacitors shall be mounted in the same way and the body clamped

Space Requirements on Printed Circuit Board

The maximum space for length ($l_{max.}$), width ($w_{max.}$), and height ($h_{max.}$) of film capacitors to take in account on the printed circuit board is shown in the drawings.

- For products with pitch ≤ 15 mm, $\Delta w = \Delta l = 0.3$ mm; $\Delta h = 0.1$ mm

Eccentricity defined as in drawing. The maximum eccentricity is smaller than or equal to the lead diameter of the product concerned.



SOLDERING

For general soldering conditions and wave soldering profile, we refer to the application note:

“Soldering Guidelines for Film Capacitors”: www.vishay.com/doc?28171

Storage Temperature

$T_{stg} = -25$ °C to $+35$ °C with RH maximum 75 % without condensation

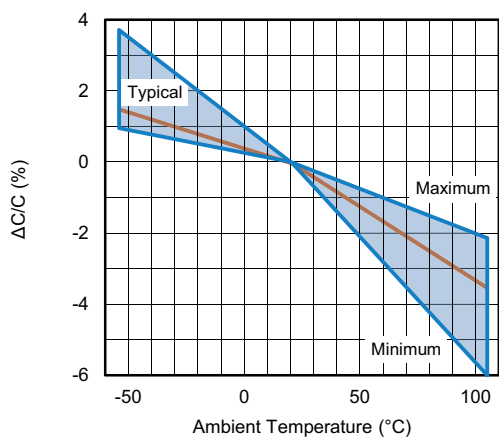
Ratings and Characteristics Reference Conditions

Unless otherwise specified, all electrical values apply to an ambient temperature of 23 °C ± 1 °C, an atmospheric pressure of 86 kPa to 106 kPa and a relative humidity of 50 % ± 2 %.

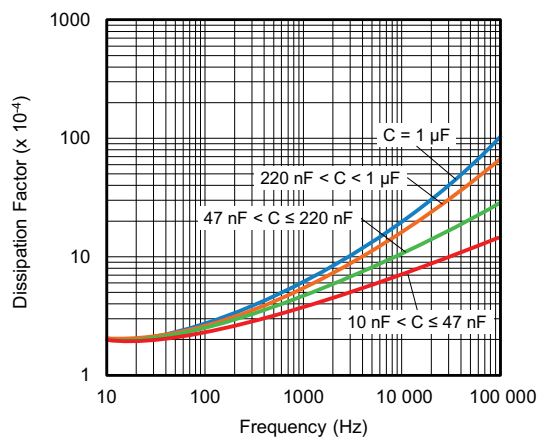
For reference testing, a conditioning period shall be applied over 96 h ± 4 h by heating the products in a circulating air oven at the rated temperature and a relative humidity not exceeding 20 %.



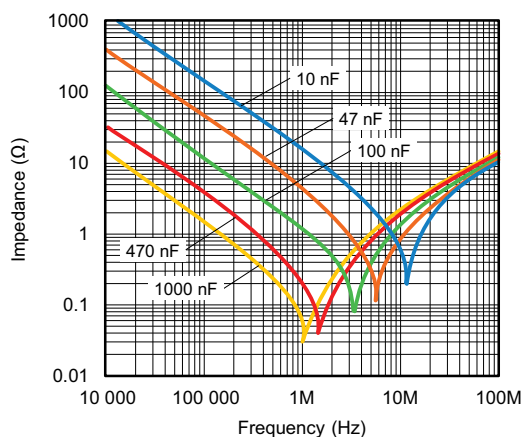
CHARACTERISTICS



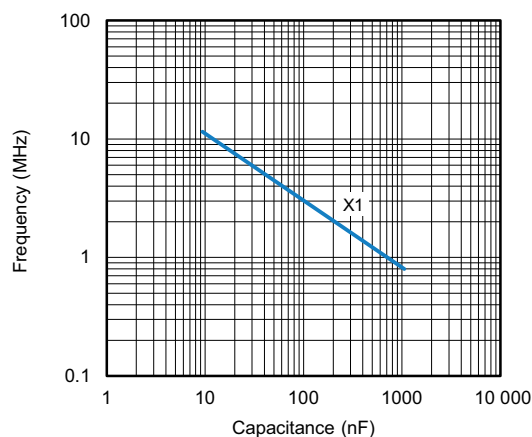
Capacitance as a function of ambient temperature (typical curve)



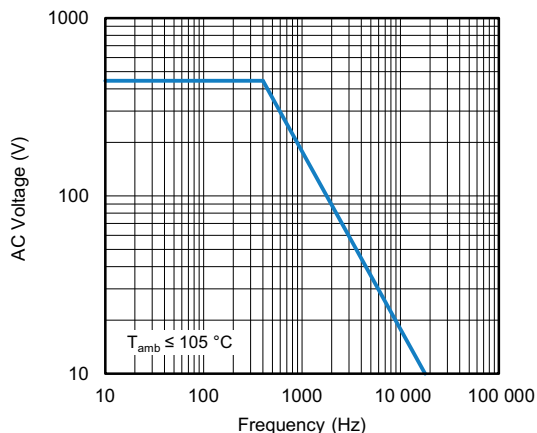
Tangent of loss angle as a function of frequency (typical curve)



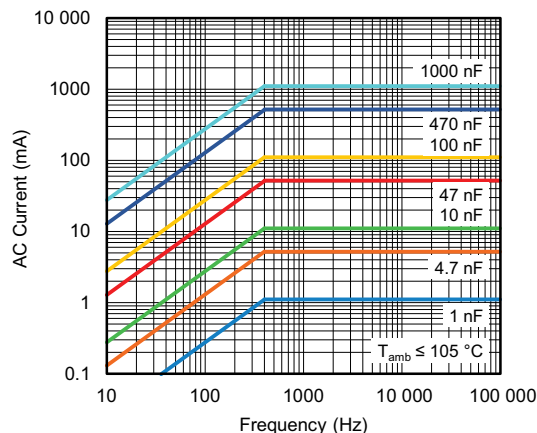
Impedance as a function of frequency (typical curve)



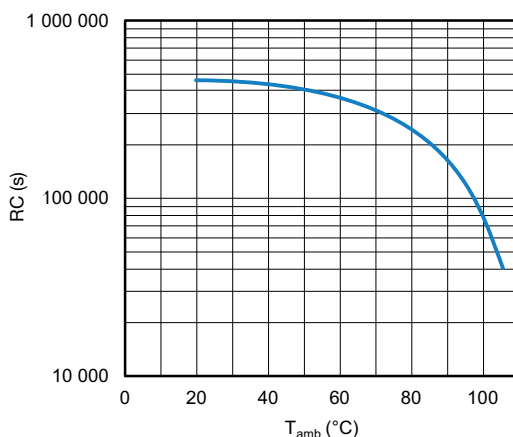
Resonant frequency as a function of capacitance (typical curve)



Max. RMS voltage as a function of frequency



Max. RMS current as a function of frequency



Insulation resistance as a function of ambient temperature

APPLICATION NOTES

- For X1 electromagnetics interference suppression in **standard across the line applications** (50 Hz/60 Hz) with a maximum mains voltage of 440 V_{AC}.
- For series impedance applications we refer to application note: www.vishay.com/doc?28153
- For capacitors connected in parallel, normally the proof voltage and possibly the rated voltage must be reduced. For information depending of the capacitance value and the number of parallel connections contact: rfi@vishay.com
- These capacitors are not intended for continuous pulse applications. For these situations, capacitors of the AC and pulse programs must be used.
- The maximum ambient temperature must not exceed 105 °C.
- Rated voltage pulse slope:
If the pulse voltage is lower than the rated voltage, the values of the specific reference data can be multiplied by 615 V_{DC} and divided by the applied voltage.

INSPECTION REQUIREMENTS

General Notes

Sub-clause numbers of tests and performance requirements refer to the “Sectional Specification, Publication IEC 60384-14 ed-3 and Specific Reference Data”.

GROUP C INSPECTION REQUIREMENTS		
SUB-CLAUSE NUMBER AND TEST	CONDITIONS	PERFORMANCE REQUIREMENTS
SUB-GROUP C1A PART OF SAMPLE OF SUB-GROUP C1		
4.1 Dimensions (detail)		As specified in chapters “General data” of this specification
Initial measurements	Capacitance Tangent of loss angle at 10 kHz	
4.3 Robustness of terminations	Tensile: Load 10 N; 10 s Bending: Load 5 N; 4 x 90°	No visible damage
4.4 Resistance to soldering heat	No pre-drying Method: 1A Solder bath: 280 °C ± 5 °C Duration: 10 s	



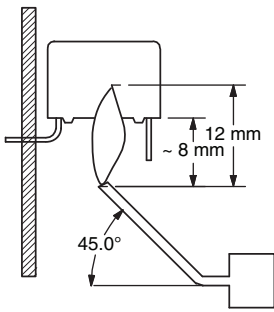
GROUP C INSPECTION REQUIREMENTS		
SUB-CLAUSE NUMBER AND TEST	CONDITIONS	PERFORMANCE REQUIREMENTS
SUB-GROUP C1A PART OF SAMPLE OF SUB-GROUP C1		
4.19 Component solvent resistance	Isopropylalcohol at room temperature Method: 2 Immersion time: 5 min ± 0.5 min Recovery time: Min. 1 h, max. 2 h	
4.4.2 Final measurements	Visual examination Capacitance Tangent of loss angle Insulation resistance	No visible damage Legible marking $ \Delta C/C \leq 5\%$ of the value measured initially Increase of $\tan \delta \leq 0.008$ Compared to values measured initially As specified in section "Insulation Resistance" of this specification
SUB-GROUP C1B PART OF SAMPLE OF SUB-GROUP C1		
Initial measurements	Capacitance Tangent of loss angle at 10 kHz	
4.20 Solvent resistance of the marking	Isopropylalcohol at room temperature Method: 1 Rubbing material: Cotton wool Immersion time: 5 min ± 0.5 min	No visible damage Legible marking
4.6 Rapid change of temperature	$\theta A = -55\text{ }^{\circ}\text{C}$ $\theta B = +105\text{ }^{\circ}\text{C}$ 5 cycles Duration $t = 30\text{ min}$	
4.6.1 Inspection 4.7 Vibration	Visual examination Mounting: See section "Mounting" of this specification Procedure B4 Frequency range: 10 Hz to 55 Hz Amplitude: 0.75 mm or acceleration 98 m/s^2 (whichever is less severe) Total duration: 6 h	No visible damage
4.7.2 Final inspection	Visual examination	No visible damage
4.9 Shock	Mounting: See section "Mounting" for more information Pulse shape: Half sine Acceleration: 490 m/s^2 Duration of pulse: 11 ms	
4.9.2 Final measurements	Visual examination Capacitance Tangent of loss angle Insulation resistance	No visible damage $ \Delta C/C \leq 5\%$ of the value measured initially Increase of $\tan \delta \leq 0.008$ Compared to values measured initially As specified in section "Insulation Resistance" of this specification



GROUP C INSPECTION REQUIREMENTS		
SUB-CLAUSE NUMBER AND TEST	CONDITIONS	PERFORMANCE REQUIREMENTS
SUB-GROUP C1 COMBINED SAMPLE OF SPECIMENS OF SUB-GROUPS C1A AND C1B		
4.11 Climatic sequence		
4.11.1 Initial measurements	Capacitance Measured in 4.4.2 and 4.9.2 Tangent of loss angle Measured initially in C1A and C1B	
4.11.2 Dry heat	Temperature: 105 °C Duration: 16 h	
4.11.3 Damp heat cyclic Test Db First cycle		
4.11.4 Cold	Temperature: - 55 °C Duration: 2 h	
4.11.5 Damp heat cyclic Test Db Remaining cycles		
4.11.6 Final measurements	Visual examination Capacitance Tangent of loss angle Voltage proof 1900 V _{DC} ; 1 min between terminations Insulation resistance	No visible damage Legible marking $ \Delta C/C \leq 5\%$ of the value measured in 4.11.1. Increase of $\tan \delta \leq 0.008$ Compared to values measured in 4.11.1. No permanent breakdown or flash-over $\geq 50\%$ of values specified in section "Insulation Resistance" of this specification
SUB-GROUP C2		
4.12 Damp heat steady state	56 days, 40 °C, 90 % to 95 % RH No load	
4.12.1 Initial measurements	Capacitance Tangent of loss angle at 1 kHz	
4.12.3 Final measurements	Visual examination Capacitance Tangent of loss angle Voltage proof 1900 V _{DC} ; 1 min between terminations Insulation resistance	No visible damage Legible marking $ \Delta C/C \leq 5\%$ of the value measured in 4.12.1. Increase of $\tan \delta \leq 0.008$ Compared to values measured in 4.12.1. No permanent breakdown or flash-over $\geq 50\%$ of values specified in section "Insulation Resistance" of this specification



GROUP C INSPECTION REQUIREMENTS		
SUB-CLAUSE NUMBER AND TEST	CONDITIONS	PERFORMANCE REQUIREMENTS
SUB-GROUP C3		
4.13.1 Initial measurements	Capacitance Tangent of loss angle at 10 kHz	
4.13 Impulse voltage	3 successive impulses, full wave, peak voltage: X1: 4 kV Max. 24 pulses	No self healing breakdowns or flash-over
4.14 Endurance	Duration: 1000 h 1.25 x U _{RAC} at 105 °C Once in every hour the voltage is increased to 1000 V _{RMS} for 0.1 s via resistor of 47 Ω ± 5 %	
4.14.7 Final measurements	Visual examination	No visible damage Legible marking
	Capacitance	$ \Delta C/C \leq 10 \%$ compared to values measured in 4.13.1.
	Tangent of loss angle	Increase of $\tan \delta \leq 0.008$ Compared to values measured in 4.13.1.
	Voltage proof 1900 V _{DC} ; 1 min between terminations 2380 V _{AC} ; 1 min between terminations and case.	No permanent breakdown or flash-over
	Insulation resistance	$\geq 50 \%$ of values specified in section "Insulation Resistance" of this specification
SUB-GROUP C4		
4.15 Charge and discharge	10 000 cycles Charged to 615 V _{DC} Discharge resistance: $R = \frac{615 V_{DC}}{1.5 \times C (dU/dt)}$	
4.15.1 Initial measurements	Capacitance Tangent of loss angle at 10 kHz	
4.15.3 Final measurements	Capacitance	$ \Delta C/C \leq 10 \%$ compared to values measured in 4.15.1.
	Tangent of loss angle	Increase of $\tan \delta \leq 0.008$ Compared to values measured in 4.15.1.
	Insulation resistance	$\geq 50 \%$ of values specified in section "Insulation Resistance" of this specification
SUB-GROUP C5		
4.16 Radio frequency characteristic	Resonance frequency	≥ 0.9 times value as specified in section "Resonant Frequency" of this specification

GROUP C INSPECTION REQUIREMENTS		
SUB-CLAUSE NUMBER AND TEST	CONDITIONS	PERFORMANCE REQUIREMENTS
SUB-GROUP C6		
4.17 Passive flammability Class B	Bore of gas jet: $\varnothing$ 0.5 mm Fuel: Butane Test duration for actual volume V in mm³: $V \leq 250$: 10 s $250 < V \leq 500$: 20 s $500 < V \leq 1750$: 30 s $V > 1750$: 60 s One flame application 	After removing test flame from capacitor, the capacitor must not continue to burn for more than 10 s. No burning particle must drop from the sample.
SUB-GROUP C7		
4.18 Active flammability	20 cycles of 4 kV discharges on the test capacitor connected to U_{RAC} .	The cheese cloth around the capacitors shall not burn with a flame. No electrical measurements are required.



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